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AVIATOR PERFORMANCE DURING DAY AND NIGHT TERRAIN FLIGHT

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December 1976

Final Report

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U. S. ARMY AEROMEDICAL RESEARCH LABORATORY
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Terrain flying, both day and night, is now an Army aviation tactical requirement. The present investigation compared terrain flight during Low Level (LL) and Nap-of-the-Earth (NOE) profiles for: (1) day flight with the unaided eye; (2) night flight with the unaided eye; and (3) night flight using night vision goggles. Data were acquired through use of the Helicopter In-Flight Monitoring System (HIMS). The total sets of inflight measures were analyzed separately for both LL and NOE with further analysis on the subsets of pilot control variables and aircraft status variables. → Next page

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SUMMARY

Terrain flying, both day and night, is now an Army aviation tactical requirement. The present investigation compared terrain flight during Low Level (LL) and Nap-of-the-Earth (NOE) profiles for: (1) day flight with the unaided eye; (2) night flight with the unaided eye; and (3) night flight using night vision goggles. Data were acquired through use of the Helicopter In-Flight Monitoring System (HIMS). The total sets of in-flight measures were analyzed separately for both LL and NOE with further analysis on the subsets of pilot control variables and aircraft status variables. Multiple discriminant analysis techniques were used to determine which measures best discriminated between visual conditions. For the LL flight profiles, the results indicate that performance factors describing air speed and the frequency of small control inputs best discriminated between visual conditions. For NOE flight profiles, it was determined that performance factors measuring severity of roll angles, and the frequency and magnitude of control input, best discriminated between the three visual conditions.

ROBERT W. BAILEY
Colonel, MSC
Commanding

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INTRODUCTION

Previous experience in Army aviation has emphasized the tactical requirement for around-the-clock operations[1]. A primary requirement in achieving 24-hour capability is development of aviator's ability to perform terrain flight profiles during both day and night operations[1]. To meet this requirement and achieve near daytime capability at night, a family of night observation devices are under development. One device presently being utilized in the aviation environment is the Night Vision Goggles (NVG's)[2,3]. The AN/PVS-5 night vision goggles were originally developed for ground use but are now considered to be an interim device to aid the pilot's night vision.

The requirement to utilize terrain flight for mission accomplishment, particularly during periods of reduced illumination, introduces major perceptual demands and physiological stress upon the Army aviator[4]. The low altitudes associated with terrain flight place an increased demand upon the visual sensory system, seriously taxing the visual resolution of navigation landmarks, targets, obstacles, and hazards[5]. Terrain flight during reduced illumination conditions further impacts the human visual sensory system by reducing the spatial and temporal resolution of this primary source of information, and by eliminating the ability to use color information[4]. These restrictions on the visual sensory system require the aviator to compensate his control input[6] and may affect the resulting man-helicopter mission capability.

The present investigation was conducted to compare terrain flying during daylight hours to that at night when the NVG's are employed. Two terrain flight profiles were selected: low level (LL) and nap-of-the-earth (NOE). Only one previous investigation has evaluated aviator flight performance with and without the aid of the NVG's. This study[6] demonstrated that the NVG's provided capability for flight at lower altitudes during NOE profiles. The lower altitude and the slower mean airspeeds demonstrated during NVG's flights required greater control workload to avoid obstacles along the NOE course. Again, during low level flights it was observed that pilots wearing NVG's generally maintained lower altitudes and slower airspeeds relative to flights using the unaided eye.

The present investigation represents a continuation of an ongoing research program to evaluate the effects of night vision goggles on aviator performance and physiology, and the resulting effects on man-helicopter system performance. In this study, terrain flight performance was examined under three visual sets: (1) unaided eye during the day; (2) unaided eye during the night; and (3) night flights using the NVG's. The NOE & LL flight profiles were evaluated to determine which performance parameters distinguished between the three types of visual sets. In addition, this research further developed the in-house knowledge base regarding aviator and aircraft in-flight performance. This particular investigation made no attempt to compare performance between LL and NOE flight profiles. Rather, this research effort focused on aviator control and aircraft response parameters within each type of flight profile.

The data base utilized for the present investigation was developed from data acquired during two field investigations, one involving terrain flight performance during the day[5]; and the second examining performance on several flight profiles at night using both the unaided eye and NVG's[4].

METHOD

Subjects

Day Flight. Subjects utilized to obtain performance data on the day terrain profiles were six experienced rotary wing aviators. These pilots had an average total of 2,249 career flight hours and had flown an average of 1,397.5 of these hours in an aircraft similar to the test aircraft. Four of the aviators had extensive NOE experience, each having flown an average of 153.7 NOE hours. The remaining two pilots had less experience with this type of flight profile.

Night Flight. Subjects utilized in obtaining the unaided eye night and the NVG's night profile performance data were six rotary wing Army aviators assigned to the Advanced Tactics Division, Department of Undergraduate Flight Training, US Army Aviation School, Fort Rucker, Alabama. These subjects were also experienced, with an average of 1,960 flight hours in rotary wing aircraft. All were experienced in nap-of-the-earth flight and had completed the Army training on this type of profile. These subjects had no prior experience with the night vision goggles.

Apparatus

Visual Device. The AN/PVS-5 night vision goggles are self contained, battery powered, passive, second generation, binocular devices (Figure 1). The NVG's used for this investigation were 40° field-of-view (FOV) goggles focused at infinity. The NVG's weigh approximately 1.9 pounds and are mounted on SPH-4 helmets with snaps and velcro attached straps (Figure 2). A more detailed description of the device can be found in USAARL Report Number 76-27[8].

Data Acquisition

The test vehicle (Figure 3) was a JUH-1H helicopter instrumented to measure and record pilot control inputs and aircraft positions, rates

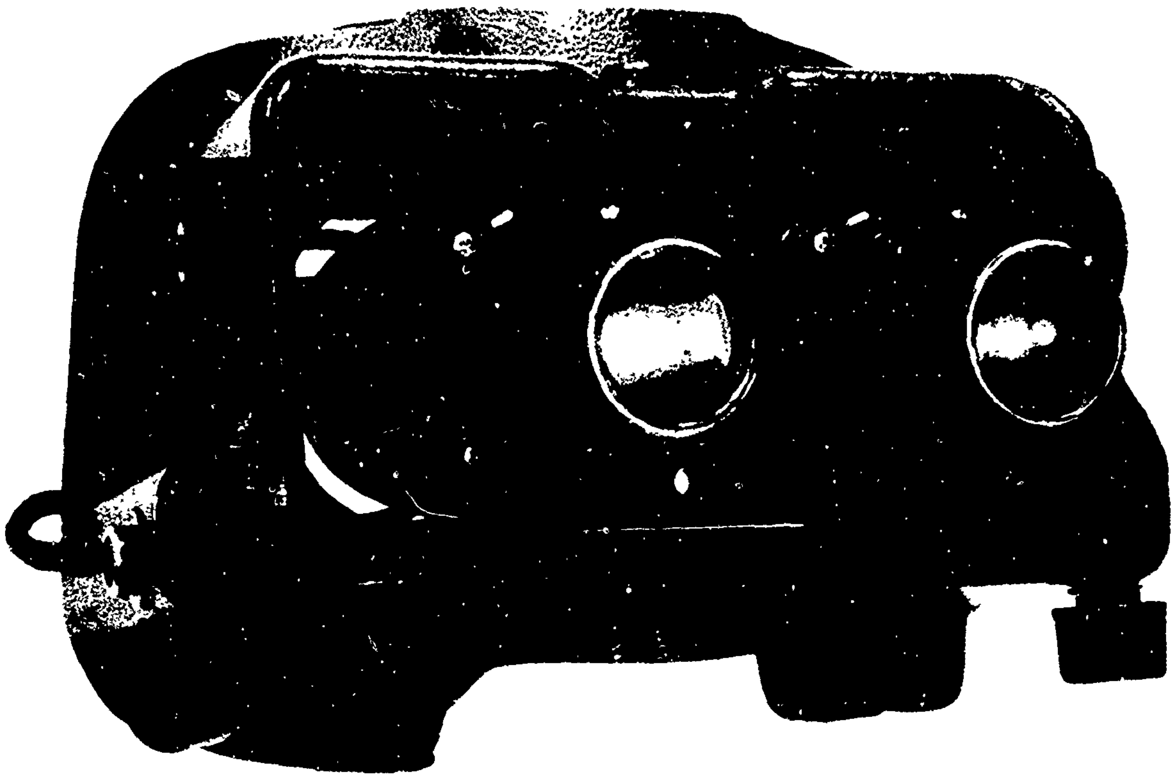


FIGURE 1. NIGHT VISION GOGGLES, AN/PVS-5

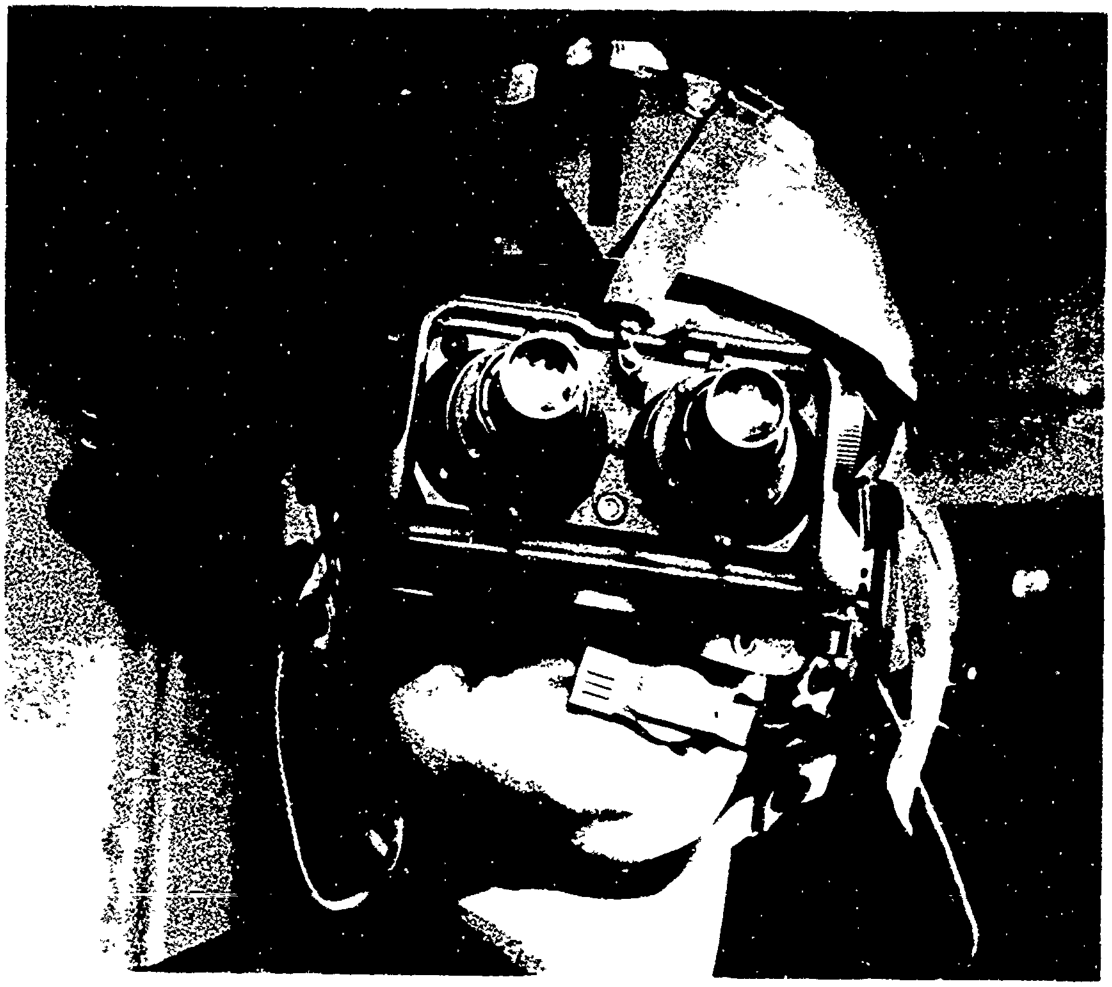


FIGURE 2.

AVIATOR WEARING NIGHT VISION GOGGLES

FIGURE 3. JUH-1H RESEARCH HELICOPTER

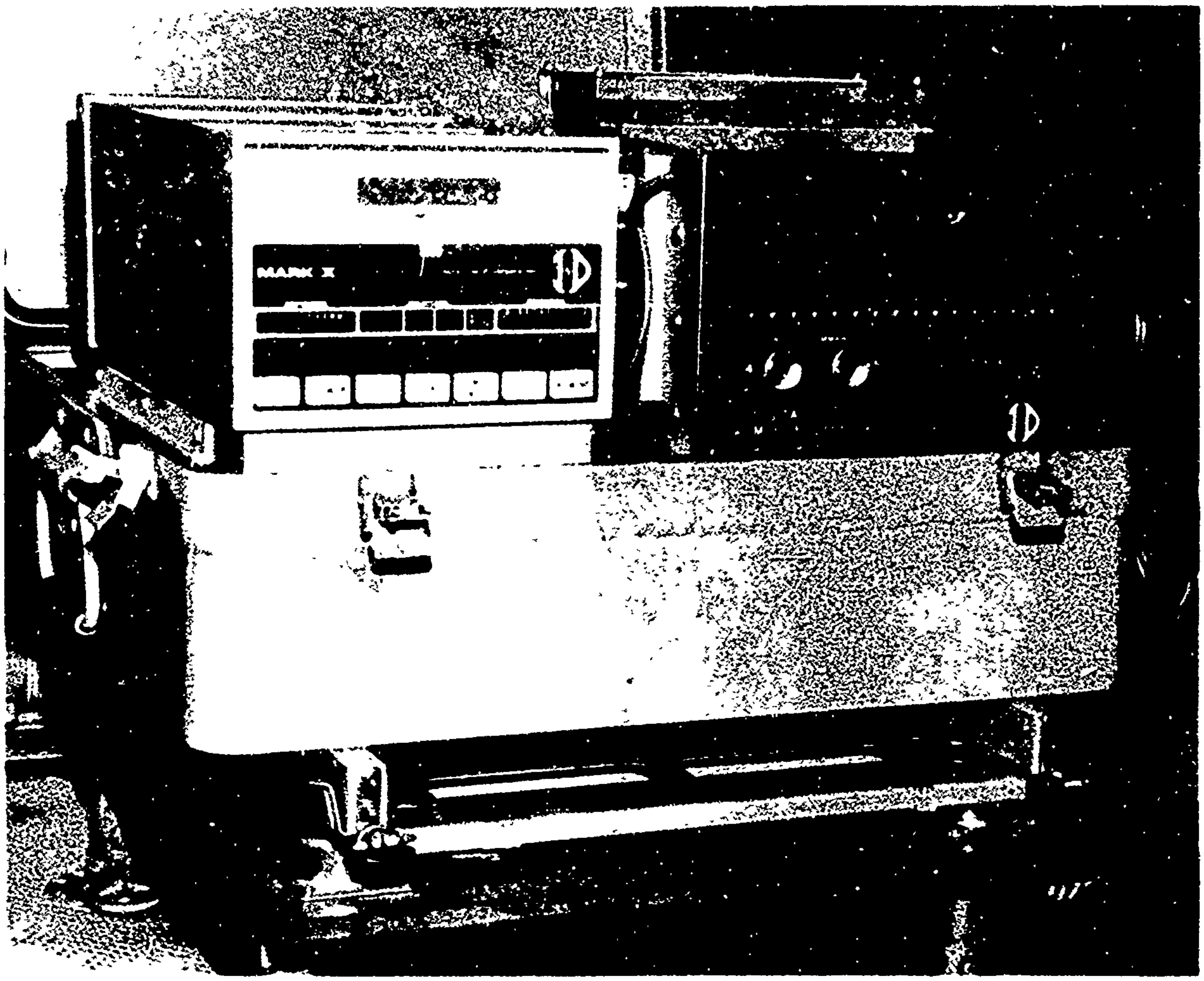


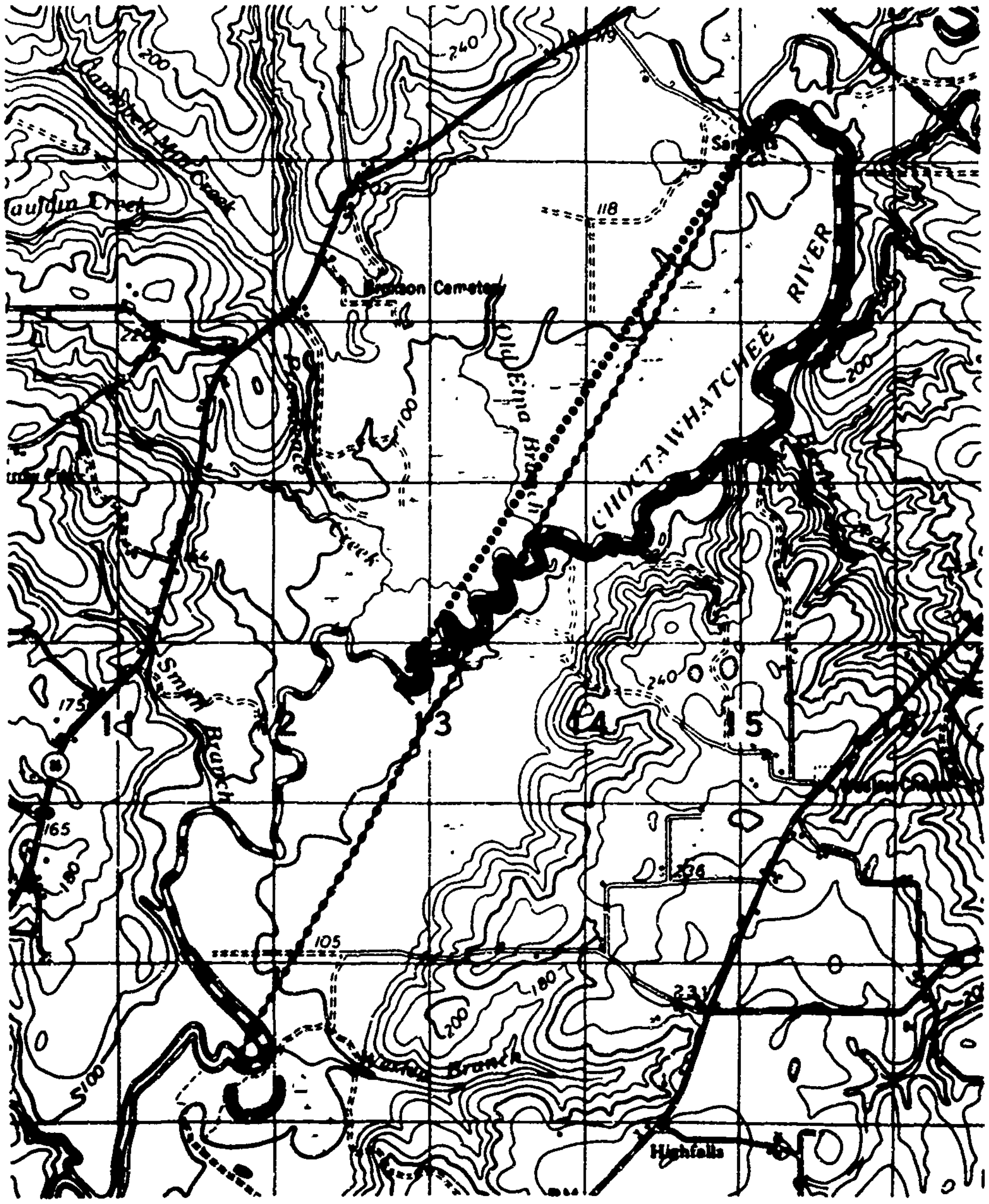
FIGURE 4. HELICOPTER IN-FLIGHT MONITORING SYSTEM (HIMS)

and accelerations. The Helicopter In-Flight Monitoring System (HIMS)[9] (Figure 4), which is integrated into the helicopter control system, measures aircraft positions in six degrees of freedom while simultaneously recording cyclic, collective, and pedal inputs and aircraft status values. These data were recorded in real time using an incremental digital recorder.

Procedure

Day Flight. For the day terrain flight profiles, the six subjects were divided into two groups of three pilots[7]. The two groups flew NOE and LL flight profiles on one day and local area flights on another day in a counterbalanced order. On the day in which subject pilots flew the NOE and LL flight profiles, they were briefed at the laboratory and then flown to the High Falls Stagefield, where testing was conducted. Each subject viewed the LL course (Figure 5) and the adjacent NOE course during a familiarization flight conducted by the safety pilot at an altitude of 500 feet MSL and an airspeed of 80 knots. After the period of orientation, the subject pilot took control of the aircraft and returned to the starting point at the same altitude and airspeed. The subject then conducted a practice flight consisting of a LL flight to the start of the NOE course, and a NOE flight through the established river course. After these familiarization runs were completed, the subject flew three recorded flights consisting of the LL segment followed by the NOE segment. Each pilot was requested to hold a specific heading and maintain an altitude of 200 feet MSL and an airspeed of 80 knots during the LL portion of the flights. This altitude placed the aircraft approximately five to forty feet above the tree cover along this route. The LL route was preselected and conformed generally to a straight line at a constant airspeed and indicated altitude. During the NOE flight, each subject was instructed to follow a segment of the Choctawhatchee River. Subject pilots were directed to maintain a track in the middle of the river such that the aircraft would be approximately 40 feet above the river bed with the rotor blades at or slightly above tree top level. Subject pilots were also asked to maintain a 45 knot airspeed although it was recognized that this airspeed could not be maintained throughout the winding NOE course. This constraint was imposed to force the pilot to make airspeed and altitude trade offs while trying to complete the course as quickly as possible and maintain maximum concealment. The NOE segment of each flight required approximately seven to eight minutes, and the low level segment took approximately two to five minutes. Data for the present investigation were taken from the final recorded LL-NOE flights.

Night Flight. During testing on the night terrain flight profiles using the unaided eye and 40° FOV NVG's, subjects were divided into two groups; one group receiving 30 minutes flight training with NVG's simulators, and the second group receiving 30 minutes laboratory familiarization with the goggles in a darkened room[6]. Prior to the LL-NOE phase of



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NIGHT NOE COURSE — DAY NOE COURSE

NIGHT LOW LEVEL COURSE — DAY LOW LEVEL COURSE

FIGURE 5. LOW LEVEL AND NOE TESTING COURSES

study, the subjects completed 65 minutes of night training and testing with three different sets of NVG's (40° FOV, 60° FOV, and 40° FOV bifocals). The preliminary test profile consisted of a set of standard maneuvers. Immediately before the LL-NOE portion of the study, the subjects were given a 20 minute refresher period with the NVG's.

During the LL-NOE phase of the study, the subjects were initially given a day orientation flight by the safety pilot over both the LL and NOE courses. The subject then flew the course at 200 feet MSL and finally made an actual LL-NOE flight under daylight conditions. Subjects were instructed to choose an altitude and airspeed which was safe and yet maintain maximum masking during all flights.

During the night testing periods, each subject flew one unaided eye LL-NOE flight, followed by one LL-NOE flight with each of the three types of goggles and then completed a final unaided eye flight. Data from this final unaided eye LL-NOE flight and from the LL-NOE flight with 40° FOV NVG's were used in the present investigation.

The LL and NOE course used in the night field investigation was approximately one-half the length of the course utilized for the day terrain flight testing. The end point of the LL course and the start point of the NOE course was identical for both studies (Figure 5).

Analysis

Separate analyses were conducted for the LL and NOE segments of each flight. Before the analysis each of the LL and NOE flight segments were standardized to insure data compatibility across the two field studies. For the NOE segments, this standardization was accomplished by selecting data that occurred between a specified point approximately .3 miles from the start of the course and a point approximately 3.5 miles from the start. In this way, the data from both field studies represented the same NOE course. Since the LL segment was used to position the aircraft at the start of the NOE segment, this course was necessarily different for the two field investigations. The LL segments were standardized by selecting segments of data which occurred during LL flight excluding the ascent during take off and descent to the NOE starting point. Absolute heading was eliminated as a possible measure of comparison between visual set conditions (i.e., day LL flight, naked eye night LL flight, or NVG's LL flight). A recording malfunction during the night and NVG's flight segments for both the LL and NOE flights reduced the test population to five subjects for the night and NVG's visual condition groups.

The initial analysis phase consisted of generating summary statistics from HIMS data collected for each LL and NOE flight segment. The available system provides 325 direct or derived measures describing pilot control inputs and aircraft position, rates and accelerations. The summary statistics from the NOE and LL flights were examined separately to determine which variables measured redundant information and which measures furnished a continuous distribution of values across the three types of visual conditions. Any measures which provided data for one type of visual condition, but which showed no observed values for the other visual conditions were eliminated from further analysis. On the basis of this examination, 64 measures were selected as appropriate for analyses of the LL flight segments and 100 measures were selected for analyzing the NOE data. These two sets (LL and NOE) of selected measures were then each further classified into two subsets which represented: (1) pilot control measures and (2) aircraft status measures.

The second analysis phase entailed submitting the LL set and the NOE set of selected measures, and each of the pilot control and aircraft status subsets to a cluster analysis program. This program developed clusters or groups of highly correlated variables. Each cluster was then considered as one independent variable and was represented in subsequent analyses by the one variable which obtained the highest cluster loading.

The unclustered variables and the variables representing each cluster were then submitted to a stepwise discriminant analysis program. This program was utilized to evaluate the ability of the in-flight performance measures to discriminate between the three visual conditions. The five most discriminating variables identified in the original stepwise discriminant analysis were re-examined with the stepwise discriminant program, without the lesser discriminating variables, thus ensuring multivariate F ratio stability.

The output of the stepwise discriminant program provides a multivariate F value for differences between the three visual conditions, a Wilk's Lambda (U-Statistic) to test the equality of visual condition group means, and an F value matrix to test the equality of group means between each pair of groups. This program also provides a classification matrix which indicates the proportion of aviators statistically classified into the appropriate visual group on the basis of the most discriminating performance measures.

The five in-flight performance measures found to be most discriminating in the stepwise analysis were then examined in Veldman's[10] multiple discriminant analysis program. This program provides univariate F ratios for each variable included, multivariate discriminant weights for each variable, a Wilk's Lambda value, an estimated Omega square, and a Chi square approximation to test the significance of each discriminant function. The Omega square value, a measure of total discriminatory power, gives an estimate of the percentage of total variability in discriminant space that is relevant to group differentiation. The primary reason for utilizing Veldman's program was to determine each variable's contribution to the discrimination of the three visual groups. This relative discrimination ability was indicated by the adjusted discriminant weights (D weights) assigned each variable for each of the discriminant functions or roots. Primary contributors to a discriminant root were considered to be those weights whose absolute values were no less than approximately one-half the largest weight.

RESULTS AND DISCUSSION

Low Level Flight

Cluster Analysis. A cluster analysis was obtained for each of the three subsets of low level flight data. The first cluster analysis examined the total set of both aircraft status and pilot control measures. The second analysis examined only pilot control measures and the third analysis examined only aircraft status measures. The subset of pilot control measures selected for further analysis is found in Table 1A. The final analysis subset obtained from the cluster analysis of aircraft status measures is presented in Table 1B. When the entire set of low level flight measures was examined, correlations between aircraft status measures and pilot control measures were utilized in developing clusters. Thus, the subset of variables selected for final analysis was somewhat different than a strict addition of the two previous variable subsets. Those variables in Tables 1A and 1B which were also selected in the cluster analysis of all low level flight measures are identified. Variables which were included in the total LL variables analysis subset but not included in either Table 1A or 1B are found in Table 1C.

Total In-Flight Variable Set. The five most discriminating in-flight performance measures taken from the entire LL variable set are referenced in Table 2A. These measures are presented in the order in which they were selected by the stepwise discriminant analysis. The multivariate F values and the Wilk's Lambda or U-statistic values are also provided in Table 2A. Using the set of variables in Table 2A, a perfect classification of each flight profile into its appropriate visual condition group was possible.

In Table 3A are found the adjusted discriminant weights for those variables that best discriminated between the visual conditions when all LL variables were considered. These weights indicate that the average or mean pitch angle of the aircraft was best able to discriminate between visual groups. Mean roll rate and mean airspeed values were also significant discriminators in identifying the different visual conditions for the LL flight profiles. In all analyses for both LL and NOE flights, only the first discriminant function or root accounted for a significant amount of the variance. Each of the variables that contributed most highly to group discrimination was related to airspeed

Table 1

Variables Selected Through Cluster Analysis Low Level Flights

A. Pilot Control Measures

1)				Cyclic Fore-Aft Control Position - Mean
2)				Cyclic Left-Right Control Position - Mean
3)	+			Collective Control Position - Mean
4)	+			Pedal Control Position - Mean
5)	+			Cyclic Fore-Aft Control Position - Standard Deviation
6)				Cyclic Left-Right Control Position - Standard Deviation
7)				Collective Control Position - Standard Deviation
8)	+			Pedal Control Position - Standard Deviation
9)	+			Cyclic Fore-Aft Absolute Control Movement Magnitude - Mean
10)	+			Cyclic Left-right Absolute Control Moevement Magnitude - Mean
11)	+			Cyclic Fore-Aft Number of Instantaneous Control Reversals
12)				Cyclic Left-Right Number of Instantaneous Control Reversals
13)	+			Collective Number of Instantaneous Control Reversals
14)	+			Pedal Number of Instantaneous Control Reversals
15)			●	Cyclic Left-Right Number of Control Reversals
16)	+	*	●	Collective Number of Control Movements
17)	+	*	●	Pedal Number of Control Movements
18)	+			Cyclic Left-Right Percent of Total Time in Control Steady State
19)	+			Collective Percent of Total Time in Control Steady State

B. Aircraft Status Measures

20)	+	*	●	Pitch - Mean
21)	+			Roll - Mean
22)	+	*	●	Pitch - Standard Deviation
23)	+			Roll - Standard Deviation
24)				Roll - Average Absolute Error (AAE)
25)			●	Pitch - Root Mean Square (RMS) Error
26)	+			Roll - Root Mean Square Error
27)	+			Heading - Standard Deviation
28)	+			Heading - RMS Error
29)				Z Axis Acceleration - Mean
30)	+			X Axis Acceleration - Standard Deviation
31)	+			Y Axis Acceleration - Standard Deviation
32)	+			Z Axis Acceleration - Standard Deviation
33)	+			Roll Rate - Mean
34)	+			Pitch Rate - Mean
35)	+	*	●	Roll Rate - RMS Error
36)	+	*	●	Pitch Rate - RMS Error
37)			●	Yaw Rate - RMS Error
38)	+	*	●	Altitude - Mean
39)	+			Altitude - Standard Deviation
40)	+	*	●	Airspeed - Mean

C. Additional Measures Resulting From the Cluster Analysis of the Total Set of Low Level Variables

1)	+	*		Cyclic Fore-Aft Number of Control Reversals
2)	+	*		Pitch - Average Absolute Error (AAE)
3)	+			Roll - AAE
4)	+			Y Axis Acceleration - Mean
5)	+			Z Axis Acceleration - Mean
6)	+			Yaw Rate - Standard Deviation

+ - Indicates that this variable was selected through cluster analysis when the total set of low level variables were considered.

● - Indicates that this variable was chosen to represent a cluster of variables within the appropriate variable subset.

* - Indicates that this variable was chosen to represent a cluster of variables when the entire set of low level variables were considered.

Table 2

Stepwise Discriminant Analysis-LL Flight Summary Data

Variable Entered	F Value	df	P	U-Statistic
A. Total Set of Inflight Variables				
1. Mean Roll Rate	90.64	2/13	< .01	.0669
2. Mean Pitch Angle	22.28	2/12	< .01	.0142
3. Collective Control Instantaneous Control Reversals - #	7.59	2/11	< .01	.0060
4. Mean Airspeed	8.39	2/10	< .01	.0022
5. Standard Deviation - Heading	5.63	2/9	< .05	.0010
B. Pilot Control Variable Set				
1. Collective Control Instantaneous Control Reversals - #	58.60	2/13	< .01	.0998
2. Cyclic Left-Right Control Control Position Mean	12.72	2/12	< .01	.0320
3. Cyclic Fore-Aft Control Instantaneous Control Reversals - #	3.05	2/11	< .10	.0206
4. Pedal Control Control Position Standard Deviation	2.45	2/10	< .25	.0138
5. Collective Control Control Position Mean	2.17	2/9	< .25	.0093
C. Aircraft Status Variables				
1. Mean - Roll Rate	90.64	2/13	< .01	.0669
2. Mean - Pitch Angle	22.28	2/12	< .01	.0142
3. Mean - Airspeed	7.18	2/11	< .01	.0062
4. Standard Deviation - Heading	3.04	2/10	< .10	.0038
5. Standard Deviation - Altitude	2.89	2/9	< .10	.0023

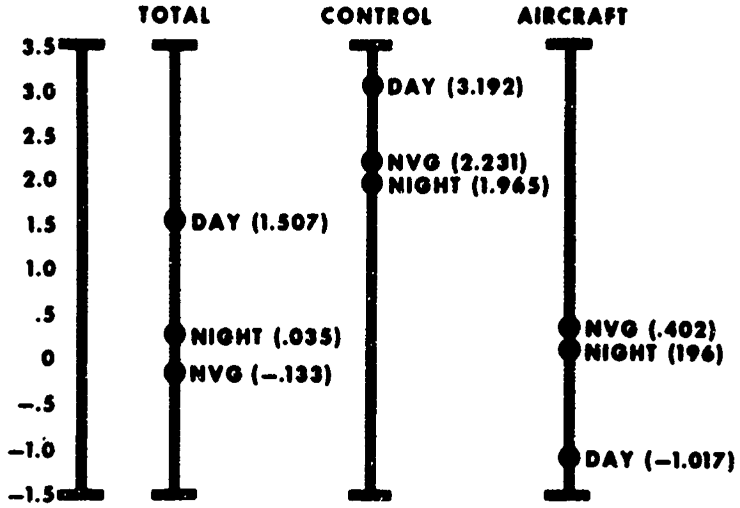
Table 3

Multiple Discriminant Analysis-LL Flight Summary Data

Variable Entered	Day Mean	Night Mean	NVG Mean	F[a]	Adjusted D Weights Root I
A. Total Set Inflight Variables					
1. Mean Roll Rate	.96	.10	.05	90.65**	.455
2. Mean Pitch Angle	-3.07	-.96	.93	25.88**	-.543
3. Collective Control-Instantaneous Control Reversals - #	684	375	444	58.59**	.151
4. Mean Airspeed	70.69	65.12	55.23	3.69	-.323
5. Standard Deviation-Heading	4.58	2.52	3.68	1.88	.212
Root I = 98.68 of variance $X^2 = 65.64$, df = 6, $p < .0001$ Total Discriminatory Power (Estimated Omega Squared) = .9988					
B. Pilot Control Measures					
1. Collective Control-Instantaneous Control Reversals - #	684	375	444	58.59**	.495
2. Cyclic Left-Right Control Position Mean	-1.35	-.63	-.63	10.16**	-.381
3. Cyclic Fore-Aft Instantaneous Control Reversals - #	428	298	364	5.34*	.314
4. Pedal Control, Control Position Standard Deviation	.293	.278	.298	.08	-.277
5. Collective Control, Control Position Mean	3.35	3.49	3.53	1.04	.136
Root I = 98.68 of variance $X^2 = 49.09$, df = 6, $p < .001$ Total Discriminatory Power (Estimated Omega Squared) = .9886					
C. Aircraft Status Values					
1. Mean Roll Rate	.96	.10	.05	90.64**	-.457
2. Mean Pitch Angle	-3.07	-.95	.93	25.88**	.477
3. Mean Airspeed	70.60	65.12	55.23	3.60	.217
4. Standard Deviation-Heading	4.58	2.57	3.67	1.07	-.158
5. Standard Deviation-Altitude	21.46	44.21	30.91	3.26	.094
Root I = 98.68 of variance $X^2 = 65.54$, df = 6, $p < .0001$ Total Discriminatory Power (Estimated Omega Squared) = .9971					

[a]Univariate F, df = 2,13 $^{**}p < .01$ $^{*}p < .05$

during actual flight conditions. It is interesting to note that unaided eye night flight more resembled day flight than did NVG's flights in terms of these airspeed related variables. This is illustrated in Figure 6 which presents the groups centroids along Root I. However, it should be noted that the two night flights are most similar and are distinct from the day flights.



GROUP CENTROID PLACEMENT ON ROOT I FOR LOW LEVEL FLIGHT DATA

FIGURE 6

<u>Pilot Control Variables</u>. The five most discriminating variables selected from the pilot control variables for distinguishing between the day, night, and NVG's flight segments are found in Table 2B. Again it was possible to perfectly classify each aviator's flight into the appropriate visual group on the basis of these five variables. Those variables showing the largest contribution to discrimination are listed in Table 3A. The number of instantaneous control reversals for the collective control and the number of instantaneous control reversals for the cyclic fore-aft control indicate that during day flights aviators made more minute adjustments in these controls during LL flight. It is notable that the next largest frequency of these control reversals was made by those aviators wearing the NVG's. The control position mean for the cyclic left/right control measure indicates that for the day LL flights, aviators increased left cyclic due to the greater airspeed of day flights as compared to either the night unaided eye flights or the NVG's flights. The lowest of the major contributors, pedal control position standard deviation, shows that during NVG's flights aviators tended to make slightly larger pedal control movements

away from average position than they did during day or night flights. The centroid placement in Figure 6 for pilot control variables demonstrates that in terms of control inputs, the NVG's flights were more similar to day flights than when the total set of LL flight variables was considered. Again it should be noted that the NVG's flights and the unaided eye night flights demonstrate the closest similarity and are obviously distinct from the day flights.

Aircraft Status Variables. The most discriminating variables selected by the stepwise discriminant analysis from the set of aircraft status values are presented in Table 2C. Perfect classification of flights into the appropriate visual condition group was obtained using the five variables.

Mean roll rate and mean pitch angle were again the two highest contributors to discrimination of visual groups, with mean airspeed providing the third largest contribution (Table 3C). It would appear that an airspeed factor, as expressed by these three variables, contributes most to overall discrimination of the three types of visual conditions. For these data, unaided eye flight at night more resembled day flights than did the NVG's flights, although the NVG's and night flights are again the most similar (Figure 6).

NOE Flight

Cluster Analysis. In Table 4 are presented the variables selected after cluster analysis of the pilot control measures (Table 4A) and the aircraft status measures for the NOE flights (Table 4B). Variables selected through the cluster analysis when the total set of NOE flight variables were considered are again identified in Table 4A and Table 4B. Those measures that were unique to the analysis of the total NOE variables set are presented in Table 4C.

Total In-Flight Variable Set. The five variables that contributed the most to discrimination between visual conditions during NOE flight segments are presented in Table 5A. On the basis of these five variables, it was not possible to obtain perfect classification of NOE flights into visual groups. One NVG's flight segment was classified as an unaided eye night flight. The addition of mean pitch rate as a classifying variable enabled perfect classification, although this procedure was not implemented due to the limited group sample size. Inspection of Table 6A shows that the five variables from the total NOE in-flight variable set did account for a highly significant amount of variance (99.86%). Of the three variables (Table 6A) which contributed most to visual group discrimination, none obtained the magnitude of adjusted D weights as observed in the LL analysis. This suggests that no individual variable or cluster of variables was able to overwhelmingly identify visual group conditions during NOE flight segments. The three variables that contributed most to the group discrimination, i.e., Y axis mean acceleration, mean

Table 4

Variables Selected Through Cluster Analysis - NOE Flights

A. Pilot Control Measures

1)	+			Cyclic Fore-Aft - Control Position Mean
2)	+			Cyclic Left-Right - Control Position Mean
3)	+	*	●	Collective - Control Position Mean
4)	+			Cyclic Fore-Aft - Control Position Standard Deviation
5)	+			Collective - Control Position Standard Deviation
6)	+	*	●	Cyclic Left-Right Absolute Control Movement Magnitude - Mean
7)	+			Collective Absolute Control Movement Magnitude - Mean
8)	+			Pedals Absolute Control Movement Magnitude - Mean
9)	+	*	●	Cyclic Fore-Aft Absolute Control Movement Magnitude - Standard Deviation
10)	+			Pedals Absolute Control Movement Magnitude - Standard Deviation
11)	+			Cyclic Left-Right Absolute Average Control Movement Rate - Mean
12)	+	*	●	Cyclic Fore-Aft Absolute Average Control Movement Rate - Standard Deviation
13)	+	*	●	Cyclic Left-Right Absolute Average Control Movement Rate - Standard Deviation
14)	+			Pedal Positive Control Movement Magnitude - Mean
15)	+			Pedal Positive Control Movement Magnitude - Standard Deviation
16)	+			Cyclic Left-Right Positive Average Control Movement Rate - Mean
17)	+			Pedal Positive Average Control Movement Rate - Mean
18)	+			Pedal Positive Average Control Movement Rate - Standard Deviation
19)	+			Cyclic Fore-Aft Negative Control Movement Magnitude - Mean
20)	+			Pedal Negative Control Movement Magnitude - Mean
21)	+			Pedal Negative Control Movement Magnitude - Standard Deviation
22)	+			Cyclic Fore-Aft Negative Average Control Movement Rate - Mean
23)	+			Cyclic Left-Right Negative Average Control Movement Rate - Mean
24)	+			Cyclic Fore-Aft Negative Average Control Movement Rate - Standard Deviation
25)	+			Cyclic Left-Right Negative Average Control Movement Rate - Standard Deviation
26)	+	*	●	Pedals Negative Average Control Movement Rate - Standard Deviation
27)	+			Cyclic Left-Right - Number of Instantaneous Control Reversals
28)	+	*	●	Cyclic Fore-Aft - Number of Control Reversals
29)	+	*	●	Collective - Number of Control Movements
30)	+	*	●	Pedals - Number of Control Movements

B. Aircraft Status Measures - NOE

31)	+			Roll - Mean
32)				Pitch - Standard Deviation
33)			●	Pitch - Average Absolute Error
34)	+		●	Heading - Mean
35)	+	*		Heading - Standard Deviation
36)	+			Y Axis Acceleration - Mean
37)	+			X Axis Acceleration - Standard Deviation
38)	+			Y Axis Acceleration - Standard Deviation
39)	+			Roll Rate - Mean
40)	+			Pitch Rate - Mean
41)	+			Yaw Rate - Mean
42)			●	Yaw Rate - Standard Deviation
43)			●	Roll Rate - Root Mean Square Error
44)	+	*	●	Altitude - Mean
45)	+			Altitude - Standard Deviation
46)	+			Airspeed - Standard Deviation

C. Additional Measures Resulting From the Cluster Analysis of the Total NOE Measures

1)	+	*	Pitch - Root Mean Square Error
2)	+	*	Roll - Root Mean Square Error
3)	+	*	Pitch Rate - Average Absolute Error

+ - Indicates that this variable was selected through by cluster analysis when the total set of NOE variables were clustered.

● - Indicates that this variable was chosen to represent a cluster of variables within the appropriate variable subset.

* - Indicates that the variable was chosen to represent a cluster of variables when the entire set of NOE variables were considered.

Table 5

Stepwise Discriminant Analysis NOE Flight Summary Data

Variable Entered	F Value	df	P	U-Statistic
A. Total Set of Inflight Variables				
1. Y Axis - Mean Acceleration	57.58	2/13	< .01	.1014
2. Mean Roll Rate	16.56	2/12	< .01	.0270
3. Mean Roll Angle	11.11	2/11	< .01	.0089
4. Collective Control-Absolute Control Movement Magnitude Mean	6.64	2/10	< .05	.0038
5. Pedal Control-Absolute Control Movement Magnitude Standard Deviation	10.20	2/9	< .01	.0012
B. Pilot Control Variables				
1. Collective Control-Mean Control Position	23.07	2/13	< .01	.2198
2. Cyclic Left-Right Control Absolute Average Movement Rate Mean	7.80	2/12	< .01	.0955
3. Pedal Control-Positive Control Movement Magnitude Mean	5.00	2/11	< .05	.0500
4. Pedal Control-Absolute Control Movement Magnitude Mean	3.05	2/10	< .10	.0311
5. Cyclic Left-Right Control Position Mean	2.43	2/9	< .25	.0202
C. Aircraft Status Values				
1. Y Axis - mean acceleration	57.58	2/13	< .01	.1014
2. Mean Roll Rate	16.56	2/12	< .01	.0270
3. Mean Roll Angle	11.11	2/11	< .01	.0089
4. Standard Deviation Airspeed	5.89	2/10	< .05	.0041
5. Mean Heading	4.01	2/9	< .10	.0022

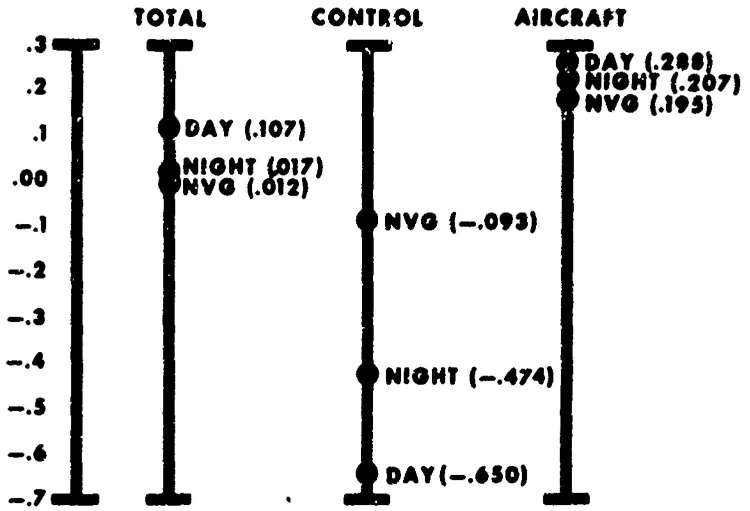
Table 6

Multiple Discriminant Analysis - NOE Flight Summary Data

Variable Entered	Day Mean	Night Mean	NVG Mean	F[a]	Adjusted D Weights Root I
A. Total inflight Variable Sets					
1. Y Axis - Mean Acceleration	.055	-.010	-.016	57.59**	.044
2. Mean Roll Rate	.881	.114	.033	19.61**	.042
3. Mean Roll Angle	.502	-1.505	-1.841	9.16**	-.034
4. Collective Control Absolute Movement Magnitude - Mean	.644	.559	.417	3.19	.018
5. Pedal Control Absolute Control Movement Magnitude - Standard Deviation	.339	.637	.334	3.56	-.013
Root I = 99.85% of variance $X^2 = 74.46$, df = 6, $p < .0001$					
Total Discriminatory Power (Estimated Omega Squared) = .9986					
B. Pilot Control Variables					
1. Collective Control Position Mean	2.958	3.650	4.032	23.07**	.466
2. Cyclic Left-Right Control Movement Rate Mean	4.458	4.885	4.892	4.31	-.358
3. Pedal Control - Positive Control Movement Magnitude Mean	.614	.756	.461	3.93	-.342
4. Pedal Control - Absolute Control Movement Magnitude Mean	.618	.699	.543	2.04	.223
5. Cyclic Left-Right Control Position Mean	-1.598	-1.154	-1.147	6.69*	.111
Root I = 93.67% of variance $X^2 = 36.56$, df = 6, $p < .0001$					
Total Discriminatory Power (Estimated Omega Squared) = .9752					
C. Aircraft Status Values					
1. Y Axis - Mean Acceleration	.055	-.010	-.016	57.58**	.044
2. Mean Roll Rate	.881	.114	.033	19.61**	.037
3. Mean Roll Angle	.502	-1.505	-1.841	9.16**	-.023
4. Standard Deviation Airspeed	4.717	7.389	4.575	6.73**	.085
5. Mean Heading	214	215	211	1.07	.012
Root I = 98.28% of variance $X^2 = 58.99$, df = 6, $p < .001$					
Total Discriminatory Power (Estimated Omega Squared) = .9973					

[a]Univariate F value, df = 2,13 $^{**}p < .01$, $^{*}p < .05$

roll rate, and mean roll angle, were interpreted to represent a roll severity factor. The day group of flights demonstrated the largest values for this factor. The position of group centroids in Figure 7, for the total NOE variables, illustrates the close similarity of night and NVG's flights.



GROUP CENTROID PLACEMENT ON ROOT I
FOR NOE FLIGHT DATA

FIGURE 7

An examination of the group means (Table 6) provides several interesting results. These data demonstrate that the severity of roll angle increased during the day flights as compared to night and NVG's flights. In addition, these values indicate that the average direction of roll angle changed from right roll angle during the day to left roll angle at night. This finding is somewhat surprising in that it suggests that the pilot, flying from the right seat, tends to roll the aircraft more to the side of greatest visibility (right side) during the day and to the least visible side (left) during the night and when using NVG's. However, subjects' comments about the NOE flights indicate that they flew closer to the right side of the river course during the night and NVG's flights to obtain better clearance and obstacle definition, thus limiting right roll.

Pilot Control Variables. The most discriminating variables within the set of NOE pilot control measures are presented in Table 5B. Perfect classification of visual groups was accomplished using these variables. The relative contribution of these variables to group discrimination is indicated in Table 6B. The increased magnitude of the adjusted discriminant weights demonstrates an increased contribution by specific variables. That is, particular variables have increased importance in describing visual group discrimination. The three variables that contributed most to group discrimination were collective control position mean, cyclic left/right average absolute control movement rate, and mean positive control movement magnitude for the pedals. It is believed that the measure of mean collective control position does not actually provide a practical discrimination of visual conditions as much as it represents a lack of success in completely counterbalancing the fuel loads carried during the different profiles. However, the other variables that showed substantial discrimination; average absolute control movement rate for the cyclic left/right control, and average absolute and average positive control movement magnitudes for the pedal control; do provide a valuable insight into performance during the different visual conditions. The group means (Table 6) demonstrate that aviators during the unaided eye night flights, produced more frequent cyclic left/right movements and a greater magnitude of pedal control inputs. These results can be interpreted as representing a condition wherein the pilot, making an unaided eye night flight, introduces a degree of overcontrol to accommodate for the lack of visual cues. It can be seen in Figure 7 that this set of pilot control variables produces a better separation of visual conditions than does either the total set of NOE in-flight variables or the set of aircraft status variables.

Aircraft Status Variables. The five most discriminating aircraft status variables are found in Table 5C. Results presented in Table 6C demonstrate the relative contribution of these variables to overall discrimination of the NOE visual conditions. Perfect classification of flight segments into the appropriate visual condition group was accomplished using these variables. The specific variables and their relative contribution to discrimination are identical with respect to the total NOE variable set. Examination of Figure 7 illustrates that separation of the groups was slightly poorer when using only aircraft status values as opposed to the total NOE in-flight variable set.

CONCLUSIONS

The substantial differences between straight and level flight and terrain flight have been acknowledged by many Army aviators. Although the tactical importance of terrain flight, particularly with night vision devices, is solidly recognized; only limited knowledge is available regarding the impact of terrain flight upon man-helicopter system performance. Previous studies have emphasized the increased sensory demands associated with terrain flight. It has also been demonstrated that the man-helicopter system performance is affected by the increased sensory restrictions inherent in night flight. The current investigation was conducted to further examine changes during in-flight performance associated with unaided eye flight during the day and night and flight with the night vision goggles.

This investigation demonstrates that for LL flights, the major factors that discriminated day flights from either night flights or NVG's flights were airspeed related variables and the frequency of small corrective control inputs. The highest airspeeds and the largest number of small corrective control inputs were observed during the unaided eye day flights. Comparison of the centroids for the three LL flight conditions demonstrates that unaided eye night flights and flights with the NVG's were similar and distinct from unaided eye day flight. However, it is noteworthy that NVG's flights more resembled day flight than did the unaided eye night flights. This relative ranking of the performance measures corresponds directly to the resolution capability of the visual system and suggests that the use of NVG's permitted the aviator to more effectively monitor and respond to minor out-of-tolerance conditions than did the unaided eye at night.

The analyses of the NOE flights demonstrated that two broad factors: (1) severity of roll through the NOE course, and (2) the frequency and magnitude of control inputs; exemplified the primary differences in performance across the three visual conditions. During the day flights, pilots utilized the most severe roll angles and tended to roll more to the right. At night with the unaided eye and NVG's, the severity of roll decreased and pilots tended to avoid excessive right roll. This difference between the day and night NOE flights is a clear demonstration of control compensation for restrictive visual conditions. At night the pilots flew closer to the right side of the river course to obtain better obstacle definition, thus limiting the amount of right roll. The unaided eye flights at night demonstrated the largest rate of cyclic left/right control movements and the largest magnitude of pedal control inputs. This indicates a degree of over-control, resulting from the decreased resolution of the visual system and the impact upon the aviator's ability to identify out-of-tolerance conditions.

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ARL 77-3

U. S. Army Aeromedical Research Laboratory, Fort Rucker, AL
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